THE CORONAL ATMOSPHERE OF THE SUN[*]

II.

WHEN the subject is a phenomenon so complex as that of the corona, it is necessary to bring to bear upon it various methods of study. This is why I have thought it indispensable to consider the corona from the triple standpoint of its aspect, the analysis of its light, and its polariscopic manifestations. Let us discuss these varied observations.

Let us first of all see what can be learned from an examination of the corona during the first instants of totality. We have seen that the general structure of the corona persisted throughout the duration of totality. We cannot, then, admit here any effect of diffraction engendered at the surface of the lunar screen by the rays grazing the edges of that screen Let us revert to the geometric circumstances of a total eclipse. At the moment when totality is produced, the disc of the moon is tangent, at one point, to that of the sun, and edges off gradually more and more to the opposite point. Diffraction will be produced, then, under physical conditions the most different, at various points of the lunar limb, and an aureole due to that cause will reveal, by its dissymmetry, such a diversity of conditions. Moreover, an aureole of this kind will present a continually varying aspect during the various phases of totality. Unsymmetrical at the outset, it will be modified with the movement of the moon, and will tend to assume the same form all round our satellite, when the disc of the latter is equidistant from that of the sun. Finally, from that point this aureole will pass through the same phases inversely until the reappearance of the sun.

However, nothing like this was produced at Shoolor. The general structure of the corona remained the same throughout the continuance of totality.[†]

It is unnecessary to dwell on the hypothesis of an aureole produced by a lunar atmosphere. We know now that if a gaseous layer exists on the surface of our satellite, it must be of so small extent that the grand phenomenon of a corona could not be produced by it.

Our own atmosphere cannot be adduced as the cause of the phenomenon, though it is evident that it plays an important part in the particular aspects which the corona may present at different stations, according to the state of the sky at these stations. It acts as a modifying, but not as a producing cause.

Let us pass, meanwhile, to the spectroscopic observations. The corona presents the hydrogen lines throughout all its visible extent; in certain parts as far as to 12′ or 15′ in height. This observation is certain. The precision of the spectroscopic scales, the experience we have had in such determinations, and the care which was taken in the last observation to compare the lines of the corona with those of a protuberance, of which they are only a prolongation, leaves no doubt as to this point.

But if the corona presents the hydrogen lines, we must ask this testing question—Is this light emitted or reflected? The constitution of the coronal spectrum will afford us an answer.

If the light of the corona is reflected, this light can only have a solar origin. It proceeds from the photosphere and the chromosphere, and its spectrum ought to be that of the sun, that is, a luminous ground with obscure lines. But such is not the constitution of the coronal spectrum; that presents to us the hydrogen lines standing in strong relief on the ground; after the green line (1474) this is the most striking manifestation in the phenomenon. We must conclude that the coronal medium is self-lighted, in great part at least, and that it contains incandescent hydrogen. This first point is conclusively established. But is it to be inferred from this that the whole of the light of the corona is emitted light? Evidently not; and on this point a delicate observation in spectrum analysis and polarisation may inform us. In fact, the spectrum of the corona presented to me, besides these bright lines, many obscure lines of the solar spectrum, the line D, and some in the green. This fact proves the presence of reflected solar light. We may ask why the principal Fraünhofer lines are reduced to the line D. It should be remarked that the coronal spectrum, not being very luminous, is especially perceptible in its central part, and that, in this part, the lines C, F, &c., are replaced by the bright lines. In these conditions the line D alone remains important; thus it is on it I have directed all my attention. As to the finer lines, they were much more difficult to discern, a fact very easily explained by the very large opening I was obliged to give to the slit of the spectroscope.

The proof of the existence of the Fraünhofer lines in the spectrum of the corona is a work of delicacy; it was not obtained by the other observers. This fact is explained partly by the great purity of the sky at Shoolor, partly by the power of my instrument. I have no doubt that the observation will be confirmed by astronomers who work under conditions equally favourable.

The presence of reflected solar light in the spectrum of the corona is of great importance; it shows the double origin of this coronal light; it explains observations of polarisation which appeared irreconcilable;[*] but above all, it enables us to understand how the solar light forming in some sort the ground of the spectrum of the corona, this spectrum may be considered continuous; and we know that hitherto this circumstance has been the great obstacle which prevented the corona from being regarded as entirely gaseous. The phenomena of polarisation presented by the corona are for the most part those of radial polarisation, which shows that reflection takes place chiefly in the corona, and that that which may be produced in our atmosphere is only secondary. Polarisation then agrees here with my observation of the Fraünhofer lines; but in order that the agreement may be complete, it is necessary that the polariscopic analysis, like the spectral analysis, should show that the light of the corona is only partially reflected. This is precisely what happened. We have seen, in fact, that near the limb of the moon, where the coronal light is brightest, polarisation appears less pronounced than at a certain distance. The reason is, that in the inferior regions emission is so strong that it conceals reflection, and the latter appears, with its peculiar characteristics, only in the layers where it is able to assume a certain relative importance.

Thus the two analyses, spectral and polariscopic, fairly interpreted, agree as to the double origin of the coronal light, and all the observations unite in demonstrating the existence of this circumsolar medium. This medium is distinguished both by its temperature and by its density from the chromosphere, of which the limit, moreover, is perfectly distinct, as is shown in all the drawings of the protuberances and of the chromosphere. There is thus a necessity for giving it a name: I propose that of "coronal envelope" or "coronal atmosphere," to remind us that the luminous phenomena of the corona owe to it their origin.

The density of the coronal atmosphere must be excessively rare. In fact, it is known that the spectrum of the chromosphere in its superior parts is that of a hydrogen medium successively rarified; but as the coronal medium, according to the indications of the spectrum, ought to be even infinitely less dense, we see how rare this medium

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[*] Continued from p. 127.

[†] It is quite evident that this constancy of aspect only agrees with points of general structure sufficiently distant from the sun not to be influenced by variations of light resulting from the displacement of the moon, relatively to the low and very luminous regions of the chromosphere.

[*] If we consult the history of eclipses we shall see that observers have often obtained contrary results, which has been the means of casting a kind of discredit on this kind of observation. But if these observations are considered in view of the double nature of the light of the corona, and of the effects of our atmosphere, we shall be able to remove most of the difficulties.

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must be. This conclusion is further corroborated by astronomical observations. Science has recorded the passage of comets as only some minutes' distance from the surface of the sun; these bodies must have traversed the coronal atmosphere, and yet, notwithstanding the lightness of their mass, they did not fall into the sun.

I shall add here, as to the constitution of the coronal atmosphere, a few ideas which do not rigorously flow from my observations, but which appear to me very probable, but upon which the future must pronounce.

I said, *à propos* of the observations in the telescope, that the corona was shown at Shoolor with a form almost square, and that it was distinguished by gigantic dahlia-like petals. It is a fact that in each eclipse the figure of the corona has often varied; it has exhibited the most eccentric appearances. I have no hesitation in saying that this medium, now incontestably recognised, and which I propose to name the "coronal atmosphere," very probably does not represent the whole of the aureole which is seen during total eclipses. It is quite credible that portions of the rings or trains of the cosmical matter then become visible and thus tend to complicate the figure of the corona. It belongs to future eclipses to instruct us on this point. But with regard to the coronal medium itself, there is no doubt that it presents singular forms, which convey but little idea of an atmosphere in equilibrium. Moreover, I am inclined to admit that these appearances are produced by trains of very luminous and dense matter from the superior layers ploughing this troubled medium. The protuberant jets, which carry the hydrogen to such great heights, must have a peculiar influence upon this coronal medium, whose density is quite comparable to that of the cometary media.

It is, then, very probable that the coronal atmosphere, like the chromosphere, is very much agitated, and that it changes its shape very rapidly, which will explain how it presents different appearances every time it has been observed.

To repeat: I have been able to establish at Shoolor, by trustworthy and consistent observations, that the solar corona presents the optical characteristics of incandescent hydrogen gas, that this very rare medium extends to very variable distances from the sun, from half a radius of the sun to about double that at certain points; but I give these figures only as results of an observation, not as definitive. It is quite certain, moreover, that the height of the corona must be necessarily variable.

This result seems to be a considerable advance in the general problem of the corona. If our foreign rivals have not obtained a result so decisive[*] as those of the French mission, I believe it must be attributed to the altogether exceptional purity of the sky in the station which I chose with such pains, and also to the combined optical arrangements which gave to the luminous phenomena which it was the object to catch, an exceptional power.[†]

JANSSEN

CHRONOMETER TESTS

THE following, which has been sent us by the Scientific Editor of *Harper's Weekly*, shows with what minuteness the scientific work of this country is studied in America, and what a critical audience we have on the other side of the water:—One of the most important services that astronomy has rendered to mankind consists in the contributions it has made to the progress of navigation, and the increased security of life and property. In this field England has always taken the lead, and the efforts of Mr. Hartnup at Liverpool are a worthy continuation of the labours of Flamstead, Bradley, and Airy. While the Greenwich Observatory has caused a great improvement in the general standard of the chronometers bought for the use of the Government vessels, Mr. Hartnup has sought to effect a similar reform for the mercantile marine. He has insisted on the vital importance to ship-masters, as well as to owners and insurance companies, of the careful determination of the rates of their chronometers as affected by temperature. The makers of these instruments and the astronomers who use them carefully have always known that which captains of vessels have been very slow to profit by—*i.e.* that the chronometers are, when made, so adjusted that they keep perfect time at two temperatures, such as 55° and 85° F., while between these limits they gain, and beyond them they lose, on the true time. It is rare that this variation in the chronometer rate can be safely overlooked by a careful navigator, though it is frequently done by those whose vessels do not carry a precious burden of 1,000 or 2,000 souls. The only excuse for this neglect is the positive assurance of the maker that the chronometer is perfectly reliable—an assurance that is often fortified by very deceitful figures. The difficulty and expense of a searching investigation into the errors to which every chronometer is liable have long been supposed by the trade to stand in the way of the introduction of such chronometers only as were of approved reliability. In order to obviate the difficulty as far as possible, the Liverpool Observatory has been constructed by Mr. Hartnup specially for the purpose of studying the rates of the chronometers that may be sent thither by captains sailing from that port. The expense of the examination given to such chronometers is comparatively trifling; and the number of chronometers submitted to him has annually increased, until by reason of the recent regulations at that port the number of examinations has amounted to between 1,000 and 2,000 annually, the same instruments having been repeatedly submitted to him. The process pursued by Mr. Hartnup consists in exposing each chronometer for a week to a uniform temperature of 55°, and determining its rate each day; it is then for another week exposed to a temperature of 70°, and then to one of 85°; the next week it is returned to the temperature of 70°, and the last or fifth week it is exposed to the temperature of 55°, as at first. By means of general laws regulating the rates of chronometers it is now possible to determine what the rate will be at other temperatures than the three above mentioned, and knowing these, the navigator is able to apply the proper correction to his time-keeper so exactly that he need never mistake his position upon the ocean.

The records of the Liverpool Observatory for the past year show—1. That the rates of about 10 per cent. of the chronometers tested (those of the mercantile marine very generally have the ordinary compensation balance) are so irregular as to render the instruments entirely unfit for nautical purposes. 2. The error of adjustment for temperature of the remaining 90 per cent. is often so erroneous as to produce a change of daily rate of many seconds, when the temperature varies but little from either of the two standard points of 55° and 85°, or thereabouts. 3. That the best made and most carefully adjusted instruments gain, on the average, daily six-tenths of a second more at a temperature of 70° than at 55° or 85°. 4. That those that have the same rate at 55° and 70°, or at 70° and 85°, lose when exposed to temperatures beyond these limits at the rate of 1·5 seconds daily for a change of 15° in temperature. 5. That when the connection between temperature and daily rate has been well determined, it will remain constant in good instruments for a

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[*] M. Respighi, at Poodookotah, made observations purely spectroscopic which confirm mine; only he found the height of the corona much less, which appears to me to be due to the more feeble luminous power of his instrument.

[†] This paper contains only an analysis of my observations: I have not been able to refer in detail to those of other observers. I may cite, however, the important remarks of Mr. Lockyer on the structure of the corona, the photographs of Colonel Tennant, the polariscopic observations made at Jafna, those of Capt. Fyers, M. Oudemans, and others.

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